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LCLS Linac X-Band RF System Specifications

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Brief Summary: The Linac X-band System includes the modulator, the klystron, the waveguide and the accelerator structure. These units are assembled as a system to provide beam acceleration before the BC1 bunch compressor. This ESD specifies the specifications and plans for these systems.

More information can be found in the CDR Chapter 7, by Paul Emma.

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The X-Band RF System

The LCLS beam is run off crest on the Injector and Linac S-band RF in order to set up a particle position verses energy correlation. The correlation is used to compress the bunch when it is run through the BC-1 bunch compressor. The RF waveform is a sine shape and the correlation set up by running the bunch off crest has a large second order component, which is not very linear. The X-Band 4th harmonic RF system (LINAC-X) operating at 11.424 GHz is located between the LINAC-1 accelerating section and the BC-1 chicane and due to its higher frequency, has a much larger curvature in RF voltage with respect to time. The beam is run on the decelerating crest of the X-band RF in a 60cm long structure in order to remove most of the second order, nonlinear part of the energy correlation introduced by the S-band acceleration. The required 32MV/m of peak gradient will require 15MW of RF power delivered to the structure, thus a klystron power output of ~23MW (including parasitic losses to the structure). Engineering overhead has been added to these values and are detailed in the Table 1.

Table 1 X-band System Engineering Specifications: (includes engineering overhead)

Structure Gradient:	32 MV/m
Structure length:	62 cm
$\langle a/\lambda \rangle$:	18%
NLCTA designations:	H60VG3-FXB-003 H60VG3-6C
Structure input power:	20 MW
Structure filling time	105 ns
Waveguide system losses:	1.3 dB (estimated)
Klystron output power:	30 MW
Klystron voltage	400 kV
Pulse length:	150 ns
Rep rate	120 Hz
RF Phase	-160 deg
Voltage gain:	-19 MV (operational
RF Phase tolerance	0.5 degrees X-band, rms, shot-to-shot
RF Amplitude tolerance	0.25%, rms, shot-to-shot
RF Phase tolerance	5.0 degrees X-band, drift, slow wrt RF reference
RF Amplitude tolerance	2.5%, drift, slow wrt RF reference

The Modulator

The standard SLAC linac 5045 klystron runs at 350kV, 400 amps, and 3.5μS flat top. The pulse transformer has a 15:1 turn ratio which requires the modulator output to be run up to 23kV at 6kA. If we assume 2μS rise/fall times, the average power is 92kW.

An X-band XL4 klystron produces 50MW running at 450kV and 350 amps and by using a pulse transformer with a 19:1 turn ratio in place of the transformer mentioned above, the beam voltage can reach 450kV with a 23.5kV, 6.7kA input. Again assuming 2uS rise/fall times (with a 0.15uS flat top) the average power is 40kW. The higher turn ratio pulse transformer will increase the rise/fall times even further, but it is anticipated that by tuning of the modulator these increases can be mitigated.

The X-Band Klystron

The X-Band klystron to be used is the SLAC-built XL-4, which has been in use at SLAC for many years and has proven to be very reliable. The LCLS X-band klystron will be mounted in the location of modulator 21-2 in the main SLAC Linac.

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In a similar manner to the feedback controlled S-band stations, the X-band RF system will be run from the existing modulator and control system, see Figure 1. This allows all the features of the existing system to be retained and where necessary additional feedback systems are to be incorporated to improve system stability even further. Existing phase and amplitude detectors (PADs) will be used to adjust the phase and amplitude and are expected to be stable to within 10 picoseconds in phase and 2% in amplitude. To achieve the required 0.5° and 0.25% stability control at X-band, additional feedback will measure phase and amplitude of the input and output accelerating cells. Strict control of the accelerating structure temperature will also be employed and the information processed to more precisely adjust phase and amplitude to meet LCLS specifications. Beam based feedback for the X-band system i.e. bunch length and beam position monitor information, is not anticipated to be needed to achieve the stability requirements for LCLS.

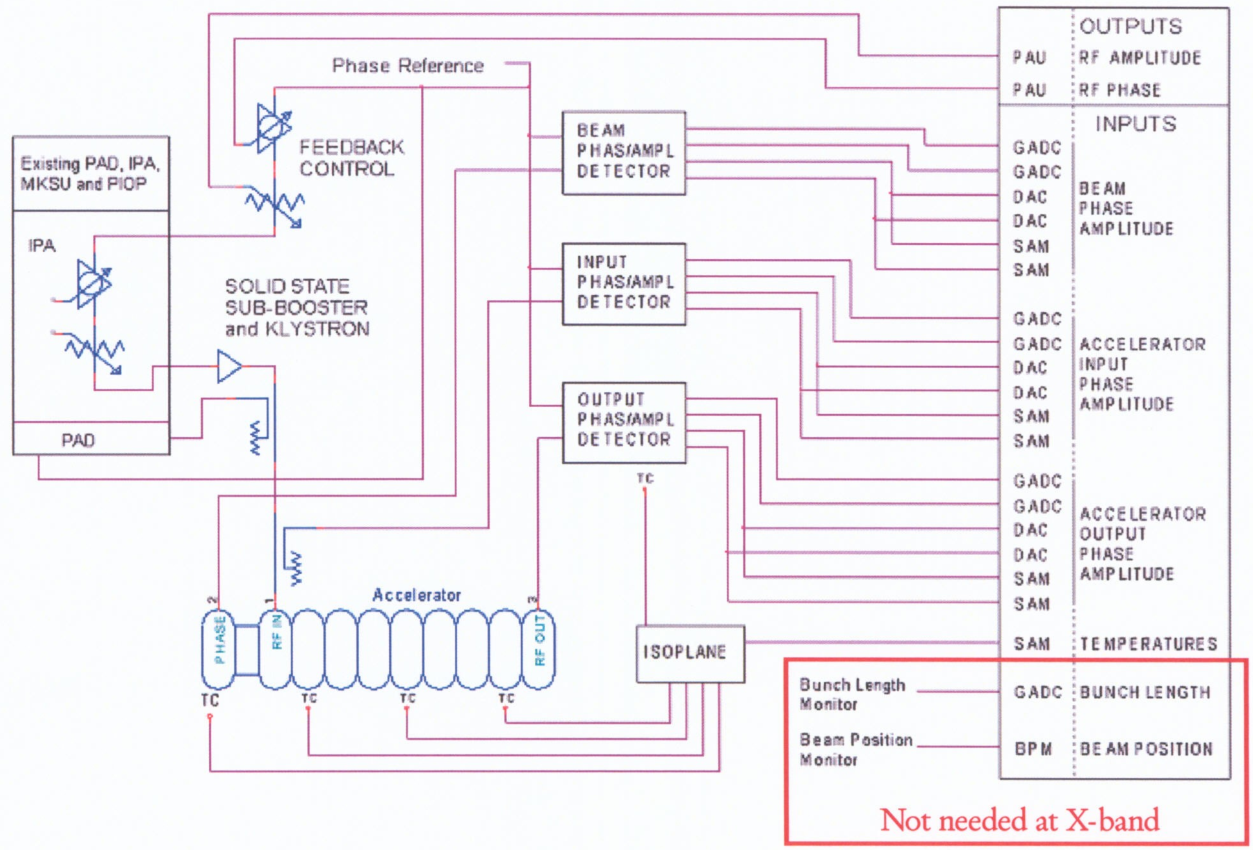

Figure 1 Single LCLS S-Band Klystron Feedback Architecture

Phase shifting will be done at the S-band level and then multiplied up to X-band, using the existing controls in the IPA chassis. The phase shift setting and read back will need to be scaled by a factor of 4 (SCP Software or hardware) and amplitude control will need to be done with an X-band attenuator after the multiplier at the mW power level. The power will then be amplified to the kW level by a TWT amplifier, which will then be used to drive the XL-4 klystron. Veneer controls at the TWT input for amplitude and phase will be used by the feedback system.

The X-Band Waveguide

The X-band klystron will be mounted in the position of klystron modulator 21-2 which is next to penetration 21-3. The system will use WR90 waveguide from the klystron to a second high power window, which will allow the klystron to be changed without venting the main LINAC vacuum. The power then enters a mode converter to cylindrical WC293 waveguide and will run from the gallery above, down to the linac tunnel below through the 25' vertical penetration. Once in the tunnel a mode converter will change back to WR90, which will then route to the accelerating structure. The structure is located approximately 3 feet over and 5 feet upstream of the penetration and there will be four high power 45dB couplers in the system, one at the klystron output, one at the accelerator input, one on the load port of the magic T and one at the accelerator output. The last two couplers will be instrumented with forward power only. The coupler at the klystron output will be used to feed into the existing control system for 21-2 klystron. The accelerator input and output couplers will be routed to the new X-band RF feedback system. The full system should give power losses of less than 1.8dB, thus to provide 15MW to the accelerating structure 23 MW is needed from the klystron. The 0.1μs, 8MW loss at 120 Hz gives an average power dissipation for the system of less than 90W.

The X-Band Accelerating Structure

The X-Band accelerating structure to be used (and a spare) have been obtained from the ILC group at SLAC and at FNAL. The structures were fabricated and run successfully as part of the testing program at NLCTA to improve accelerating gradient levels in X-band devices. At NLCTA the structures were reliably run at 65 MV/m with an input power of 63 MW. For LCLS use the X-Band structure is required to run at about half of that gradient (32 MV/m), thus ¼ of that input power is needed. These structures were designed with a value of a/λ of 18% to mitigate wakefield effects. Table 2 shows some typical X-band accelerating structure characteristics as confirmed from high power tests on NLCTA.

Table 2 X-Band Accelerating Structure Characteristics

Structure Type	H60VG3S18
Other Names	FXBs (2D), KX01 (2D)
Length	62 cm
Number of Cells	53 cells + 2 Matching Cells
Iris Radius	$<a/\lambda> = 0.18$
Phase Advance	$5\pi/6$ Per Cell
Group Velocity	3.27–1.24 % Speed of Light
Attenua-tion τ	0.533 0.508 (2D)
Filling Time	105 ns
Q_0 Value	~ 6640 ~ 6990 (2D)
Shunt Im-pedance	46.5-73.5 49.1-77.2 (2D) MΩ/m
Coupler Type	Mode Converter or Wave Guide Type
1st Band Dipole Mode Detuning	kdn/df Symmetric Gaussian $\Delta f/f \sim 10\%$ (4.0σ)
Es /Ea	2.06 - 1.90
Required Input Power	69 MW 63.2 MW (2D)
Unloaded Gradient	65 MV/m

Structure	P (MW) for 65 MV/m
H60VG3-FXB2	63
H90VG3	82
H60VG3-6C	63
H60VG3-FXB3	63